THE BELL SYSTEM TECHNICAL JOURNAL
Vol. 62, No. 6, July–August 1983
Printed in U.S.A.

Human Factors and Behavioral Science:

Effects of Shape and Size of Knobs on Maximal Hand-Turning Forces Applied by Females

By G. A. KOHL*

(Manuscript received December 23, 1981)

Outside plant craftspeople use knobs to apply turning forces on clamp mechanisms that hold field equipment temporarily in place. A study was performed to develop a set of data that provide guidance for determining knob size and shape characteristics most appropriate for various outside plant working conditions. Forty female participants applied maximal isometric turning force to each member of a set of twenty experimental knobs that systematically varied in shape and size. In half the trials the participants applied force with greased hands and in the other half used nonslip compound. In addition, two arm-wrist positions were observed. In general, triangular knobs allow more hand torque to be generated and require significantly less material than square, pentagonal, hexagonal, or circular knobs of comparable size. However, this effect depends upon the arm-wrist position and grip conditions. A 3.5-inch turning diameter is desirable when both cost and performance are considered.

I. INTRODUCTION

Outside plant craftspeople in the Bell System use knobs to apply turning forces on screw-operated clamp mechanisms used to hold heavy field equipment temporarily in place. Female craft who use these

* Bell Laboratories.

knobs report that the knobs tbey currently use do not enable them to easily generate sufficient torque to clamp down equipment. The question raised by these reports and addressed here is: What characteristics of a knob allow turning forces to be easily generated? Considering the variety of torque knobs in the world (e.g., door knobs, small valve wheels, faucets), and the considerable body of knowledge the human factors community has acquired about control knobs, it is perhaps surprising to find that the literature sheds little light on this rather straightforward and practical question (see Refs. 1 and 2 for the best existing treatments of torque knobs).

The following experiment was designed to provide a set of data that can assist designers in developing torque knobs, and we hope will be of value to the hand tool industry in general. The approach taken in this study was strictly empirical and consisted of measuring the amount of turning force tbat participants can generate using knobs of various sizes and shapes under several different conditions.

II. METHOD

2.1 Participants

Forty right-handed females from the Whippany, New Jersey, area responded to newspaper and intracompany bulletin board ads, and served as paid participants. Mean and standard deviation of the group's age, height, and weight were respectively: 37 years, SD = 13.5; 64.7 inches, SD = 3.4, and 132 pounds, SD = 27.2.

2.2 Independent variables

Variables were identified thst could affect knob-turning performance, including features of the knobs and the conditions under which the knobs might be used. To render the study manageable in size, only five of the most intuitively and/or practically relevant variables to the Bell System application were included in the study.

2.21 Knob shape

There are a limitless number of possible knob shapes. A shape sttribute, "sidedness," was chosen to succinctly capture the spectrum of shapes that could affect knob-turning performance. Five shapes were chosen, as shown in Fig. 1, varying from few sides to infinite sides (i.e., triangle, square, pentagon, bexagon and circle).

2.2.2 Knob size

An operational definition of size was generated so that knobs of different shapes could be compared. The "diameter" of a knob is the diameter of the circle bounding the outermost points of the knob. Thus the triangular knob always has about half the area of a circular

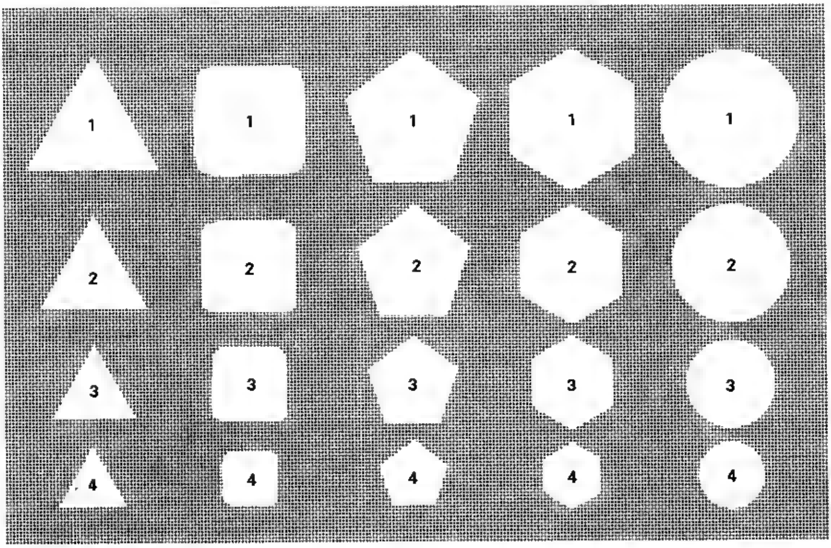

Fig. 1—The set of experimental knobs.

knob with an equivalent diameter. The definition has real-world validity in that the envelope in which a knob turns is likely to be a design constraint. Four diameter sizes were included in the study: 2.5, 3.5, 4.5, and 5.5 inches. Preliminary evidence showed these sizes to represent plausible end- and middle-point values for diameters of knobs to be used to generate turning force.

2.2.3 Grip condition

The types of knob surface conditions that could be tested are numerous, for example, knurled surfaces, serrated edges, slippery surfaces. The surfaces of the knobs in this study were all the same—smooth, anodized aluminum. However, an attempt was made to study the extremes of surface conditions by including two grip friction conditions under which the knob was turned. In the *greased* condition participants greased their hands before turning; in the *nonslip* condition they applied a nonslip compound.

2.2.4 Position

The hand-arm position was varied to emulate various real-world conditions, where knobs must be turned from many different vantage points. Two standing positions were included; in both conditions the height of the knob was adjusted to the level of the elbow joint for each participant. In the *front position* the participant stood straight in front of the knob, forearm parallel to the floor and perpendicular to the upper arm and frontal plane of the body, the axis of knob rotation

coincident with the longitudinal axis of the forearm. Tbe wrist was bent so that the band pointed up, tbe palm of the hand against the knob face, fingers spread around tbe knob edge. In the *side position* the participant stood to the side of the knob with the forearm parallel and perpendicular to the axis of rotation of the knob. The palm of the hand pressed against the face of the knob with the fingers spread around tbe knob edge.

2.2.5 Participant size

Size was included as a subject variable. Although hand size was originally targeted as the variable tbat would most affect performance, weight was found to be a better predictor.[3] Four weight groups of ten participants each were formed on a post hoc basis. Tbe mean and standard deviation of the four group's weights in pounds were: 106 pounds, SD = 5.72; 120 pounds, SD = 3.65; 132 pounds, SD = 5.87; 171 pounds, SD = 22.96.

2.3 Experimental design

A complete factorial design was employed (5 knob shapes × 4 knob sizes × 2 grip conditions × 2 positions × 4 participant weight groups). All participants were included in all possible within-participant treatment conditions.

2.4 Procedure

Each participant attended for one day on two consecutive weeks for approximately four hours each day. On each day each participant performed four blocks of twenty trials, each block consisting of one appearance of each of the twenty knobs. For each trial participants were instructed to apply maximal isometric turning force to a knob specified by the experimenter, using the right hand for a period of three one-second beats of a metronome. The order of tbe knob appearance was randomized for each block of trials for each participant. On each day, the front position was employed on two blocks of trials, the side position on the other two; one of the side position and one of the front position trial blocks were performed with a greased hand. The remaining two blocks were performed using a nonslip compound.

Participants were observed in groups of three or four, every participant performing a single trial before any given participant performed her next trial. Roughly two minutes intervened between any given participant's trials, and breaks of twenty minutes were taken between blocks of trials.

2.5 The knobs

The relative size and shape of the knobs is shown in Fig. 1. Tbey were made of machined aluminum and had an anodized smooth

surface. All corners and edges of the knobs were rounded and the smallest radius on any edge was 0.25 inch. The knobs were 1.25 inches thick.

III. RESULTS

The data were submitted to an analysis of variance,[4] with knob shape, knob size, grip conditions, position, and day of participation treated as within-subjects variables, and participant weight as a between-subjects variable. The most important results are summarized here.

The most informative effect obtained was a four-way interaction of the shape, size, position, and grip variables [$F(12,432) = 5.2$, $p < 0.00001$]. Fig. 2 shows this interaction. The top two panels show performance as a function of knob shape and size for the side position, the left panel for the nonslip blocks and tbe right panel for the greased blocks of trials. The bottom two panels show performance using the front position, the left panel for the nonslip condition and the right panel for the greased condition.

Several effects are apparent from a visual inspection of Fig. 2. The greased condition performance (right two panels) is lower than the nonslip condition [$F(1,36) = 289.6$, $p < 0.00001$]. Further, over all other variables, performance decreases as the number of knob sides increases [$F(4,144) = 183.2$, $p < 0.00001$]. This main effect is qualified by an interaction with the grip variable [$F(4,144) = 71.0$, $p < 0.00001$], indicating that the main effect of shape is much more pronounced in the greased condition than in the nonslip condition. Figure 3 shows this two-way interaction.

The effect of size is apparent in Fig. 2; across all other variables, the bigger the knob diameter, the more torque developed [$F(3,108) = 246.8$, $p < 0.00001$]. The left-to-right convergence of the curves in Fig. 2 reflects the two-way interaction of the knob size and shape variables: over all other variables, the greater tbe number of sides, the less advantage size has [$F(12,432) = 53.6$, $p < 0.00001$]. The fact that the convergence of the curves is more pronounced in tbe greased (right two panels) than the nonslip panels is reflected in a two-way interaction of knob shape, knob size, and grip condition [$F(12,432) = 8.4$, $p < 0.00001$]. The reversal of the sidedness advantage for smaller knobs in the nonslip, top left panel is counter to the patterns in the other three panels and is reflected as the four-way interaction illustrated in Fig. 2.

Participant weight was only a marginally significant main effect [$F(3,36) = 2.6$, $p < 0.07$] but did interact with the knob size variable [$F(9,108) = 4.8$, $p < 0.0001$], indicating tbat the advantage larger people have over smaller people dwindles as knob size decreases.

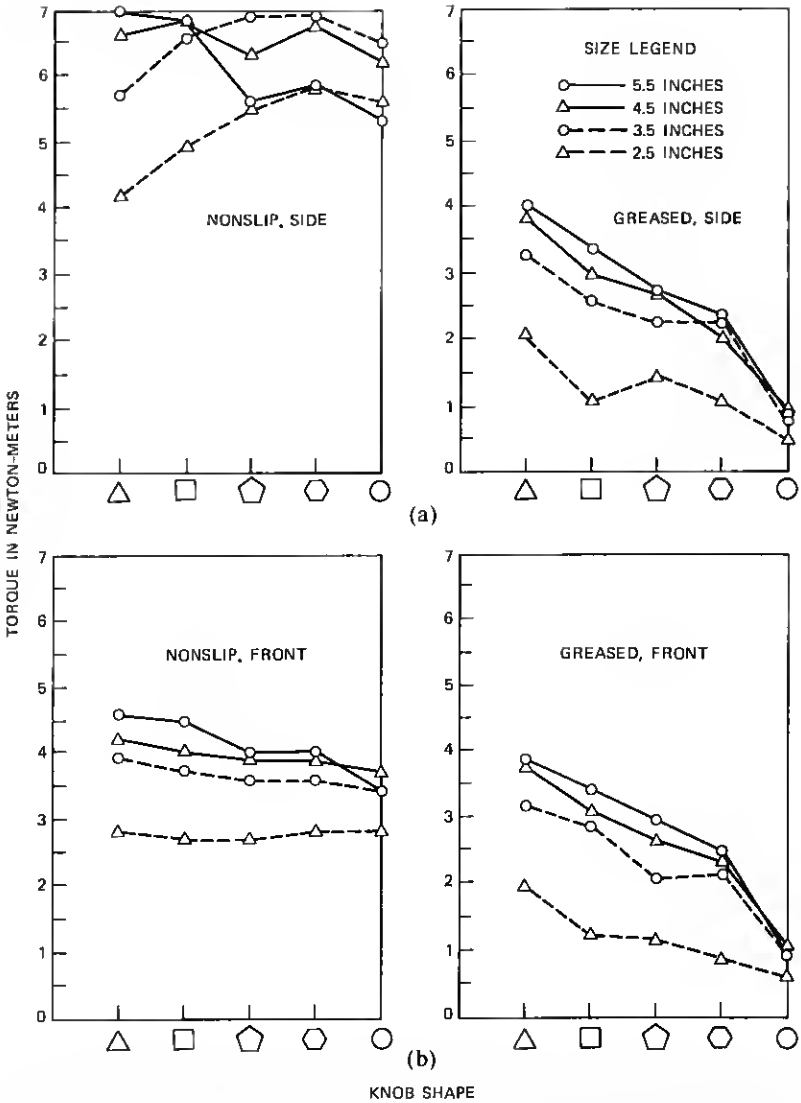

Fig. 2—Four-way interaction of the knob shape, size, position, and grip condition. (a) Performance as a function of the knob shape and size for side position. (b) Performance as a function of knob shape and size for the front position.

Several other main effects and interactions were obtained: position, day, grip × position, grip × knob size, position × knob size, position × shape, day × shape, grip × position × knob size, grip × position × shape, and position × knob size × shape.

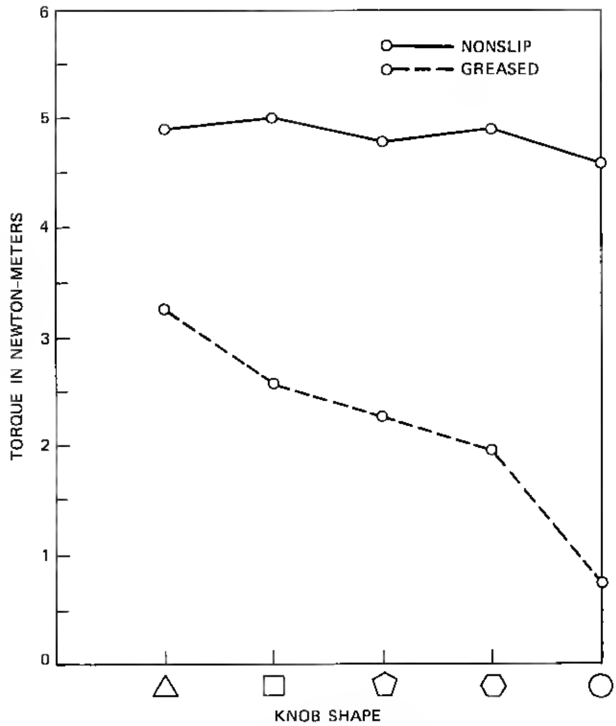

Fig. 3—Knob shape by grip condition.

IV. SUMMARY AND DISCUSSION

The practical difference between means in Fig. 2 will have to be decided by individual designers. Note that if the application involves a nonslip, front approach, the shape of the knob has little effect, and the knob size is very important (Fig. 2, bottom left panel). However, in both the front and side greased conditions, shape is very important; note the smallest triangle results in better performance than the largest circle (Fig. 2, bottom right panel). The savings in materials in this case is roughly 10 to 1.

In general, triangular knobs allow for the generation of as much or more torque than any of the other shapes. However, subjective comfort ratings indicate that the smallest triangular knob causes discomfort. Also, the smallest triangular knob does not fair well in the nonslip, side condition. Therefore, for 2.5-inch diameter applications the square is probably a better choice.

The biggest jump in performance with respect to knob diameters comes between 2.5 and 3.5 inches; thereafter performance increases as diameter increases, but at a smaller rate.

Considering materials, torque and comfort, the triangular and square 3.5-inch knobs are recommended for general application. If more torque is required than can be obtained witb these knobs, larger diameter triangular or square-shaped knobs should be used. For tbese or any other knobs, all corners and points should be rounded for best performance and comfort.

V. ACKNOWLEDGMENTS

The author expresses appreciation to Brian G. Bancroft for assisting in the development of experimental apparatus and conducting the investigation, and Elise Darrow and Ha T. Nguyen for assisting in the data analysis and preparation of this report.

REFERENCES

1. E. O. Sharp, "Maximum Torque Exertable on Knobs of Various Sizes and Rim Surfaces," MRL-TDR-62-17, Behavioral Sciences Laboratory, Aerospace Medical Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio, 1962.
2. A. D. Swain, G. C. Shelton, and L. U. Rigby, "Maximal Torque for Small Knobs Operated With and Without Gloves," Ergonomics, *13*, No. 2 (1970), pp. 201–8.
3. G. A. Kohl, unpublished work.
4. B. J. Winer, *Statistical Principles in Experimental Design* (2nd Ed.), New York: McGraw-Hill, 1971.

AUTHOR

George A. Kohl, Jr., B.S., 1968, United States Merchant Marine Academy; M.S., 1974, Experimental Psychology, Purdue University; Ph.D., 1978, Experimental Psychology, Purdue University; U.S. Merchant Marine Engineering Officer, 1968–1974; Assistant Professor of Psychology, Allentown College, 1977–1978; Bell Laboratories, 1978—. Mr. Kohl has been a Human Factors Specialist at Bell Laboratories, performing research, design, and development work on equipment and systems used by central office and outside plant craftspeople. Most recently, he has been a member of the team responsible for the design of a computerized transmission enhancement system to support special services operations. Member, American Psychological Association and the Human Factors Society.